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(54) **Alternating-current tachometer**

(57) The invention relates to an alternating-current tachometer whose output is in linear dependence in amplitude and frequency upon the rotation rate and the recognition of direction of rotation is achieved within a very narrow error range in the region of the zero point. A multi-pole winding of meander form, arranged in the air gap in a magnetic flux circuit including magnetic yokes 1, 2 and magnet 3, on non-magnetic material 8 is energised by a magnetic flux of varying intensity. The variation of the magnetic flux is here achieved by a constantly changing maximal and minimal coupling to the winding, the slot pitch corresponding to the pole pitch. The alternating magnetic couplings are achieved by appropriate grooving on the magnetic yokes of the rotating energiser circuit in the region of the air gap, whereas the winding is

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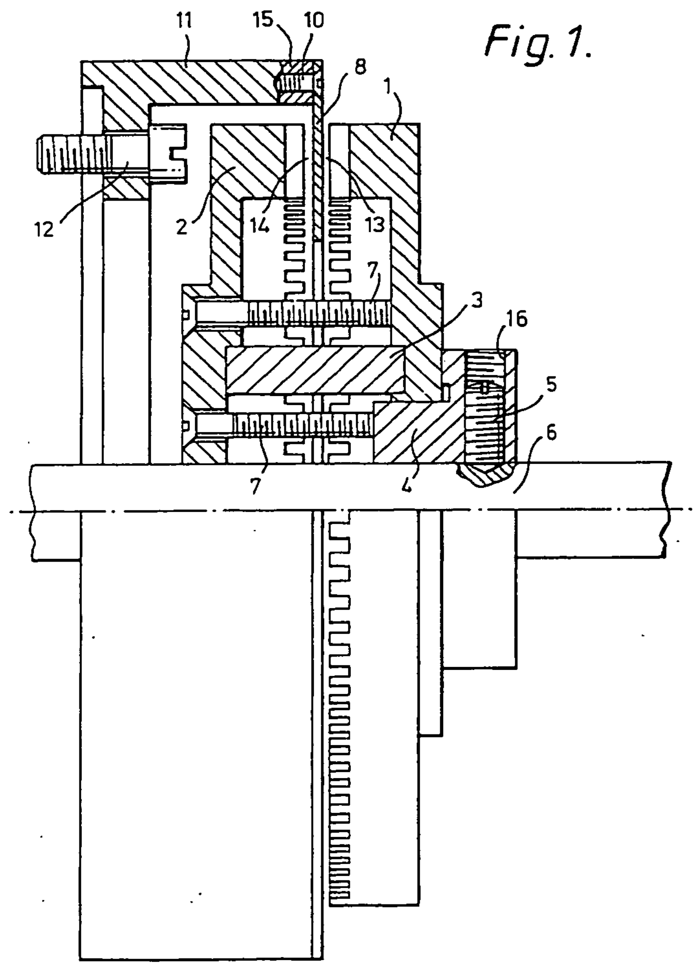

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stationary. The type of winding and the winding pitch or interval determines whether a single phase or a selected multi phase A.C. output is produced. The direction of rotation may be determined from the polarity of the rectified D.C. voltage.

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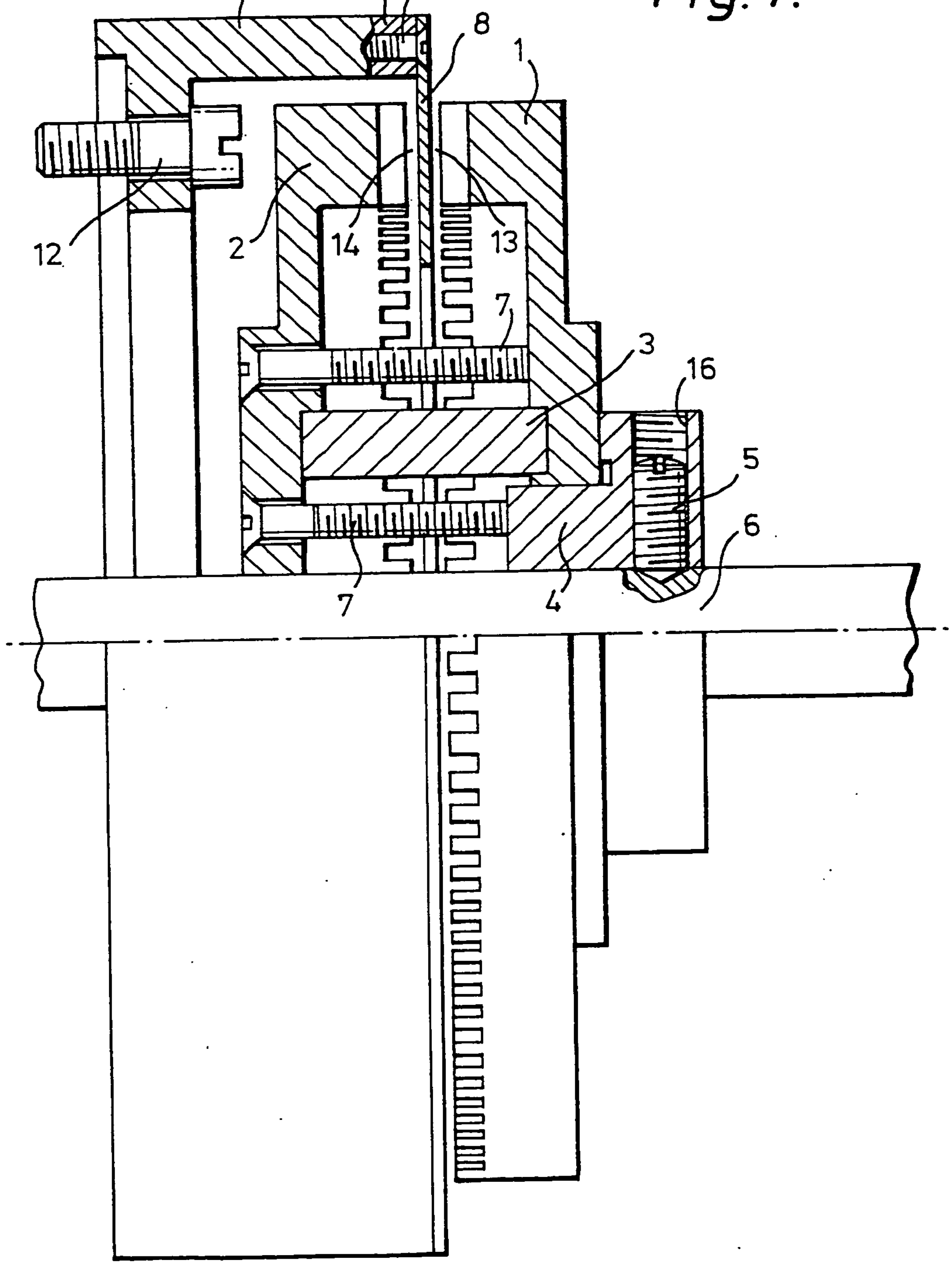
Fig. 1.



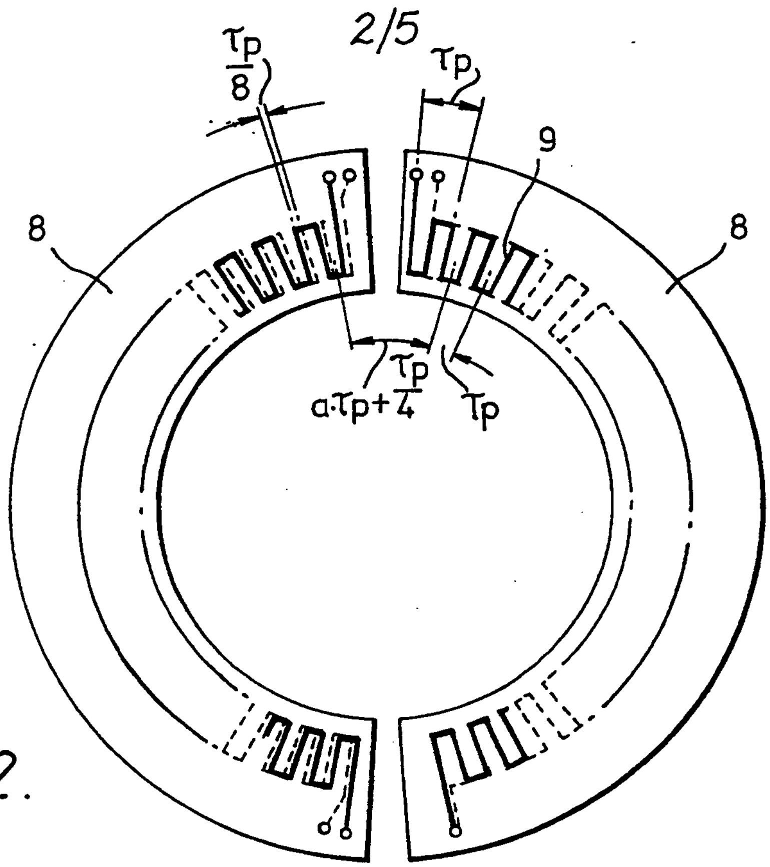

$\frac{\tau p}{8}$
τp
9
8
8
$a \cdot \tau p + \frac{\tau p}{4}$
τp

Fig. 2.

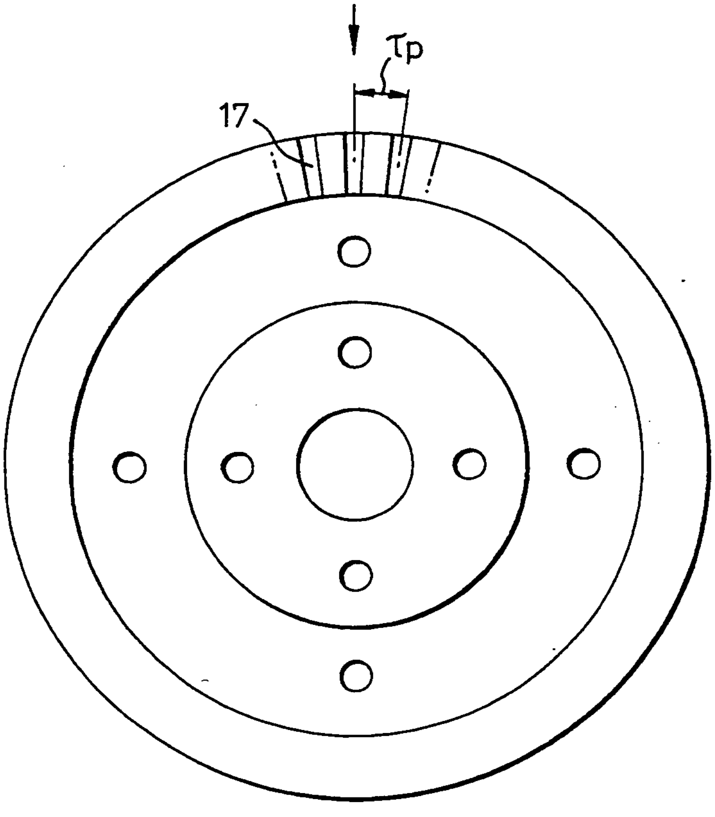
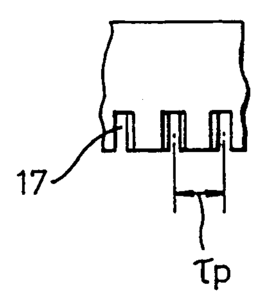

τp
17

Fig. 3.


17
τp

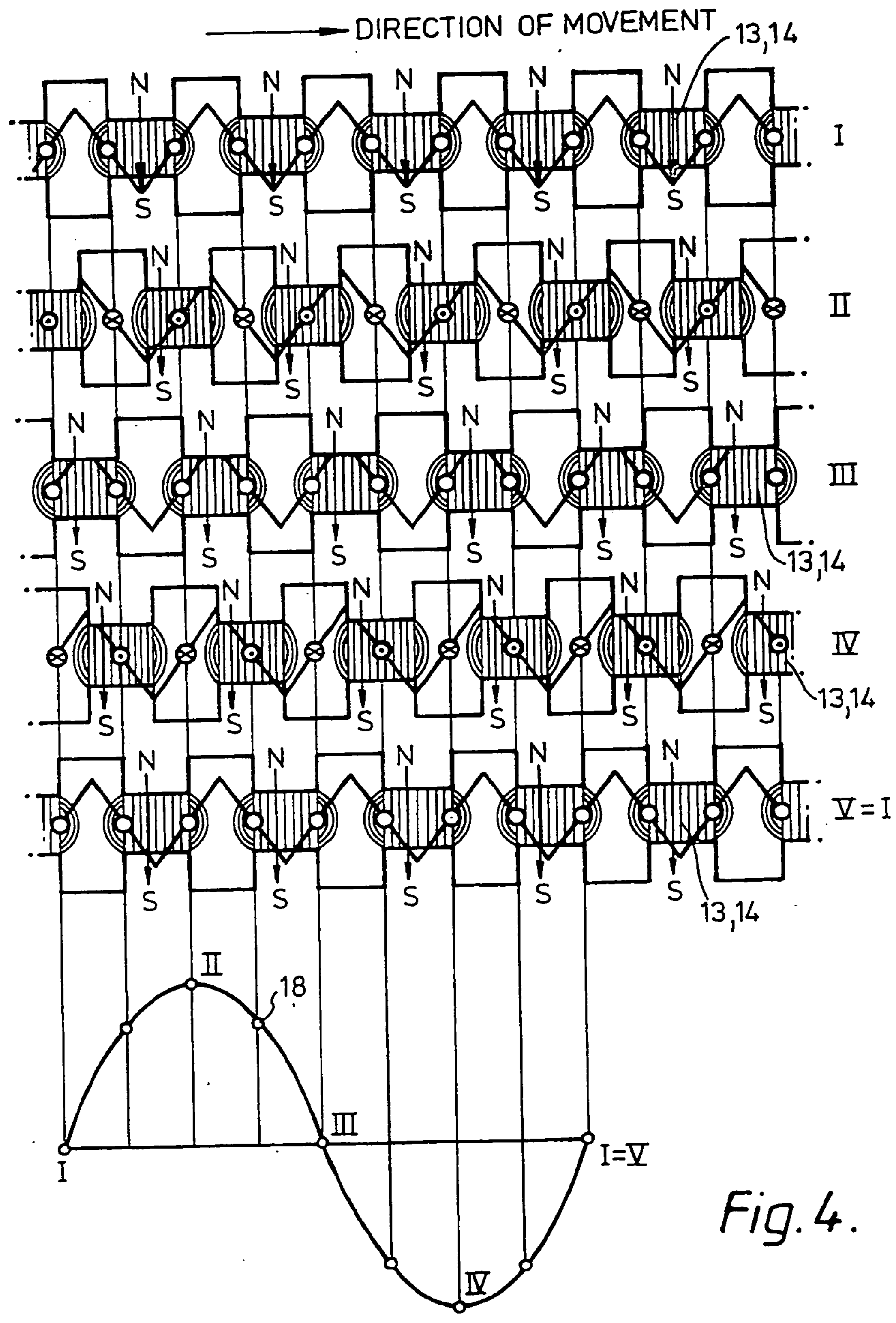


Fig. 4.

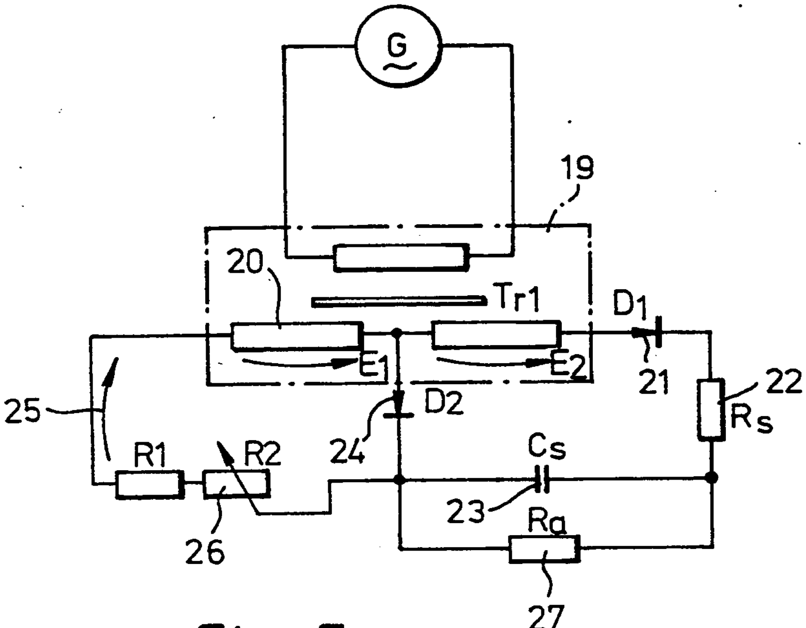


Fig. 5.

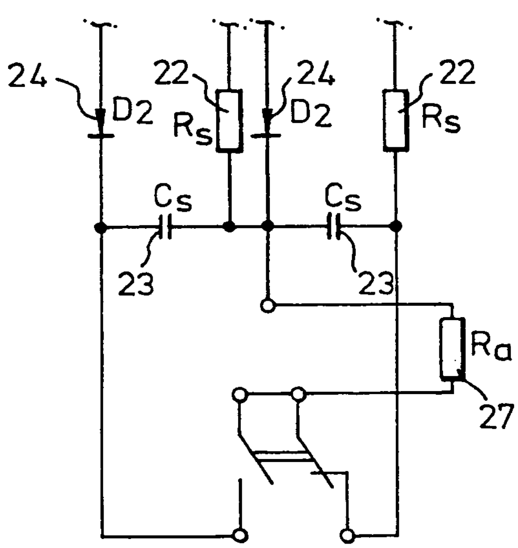


Fig. 6a.

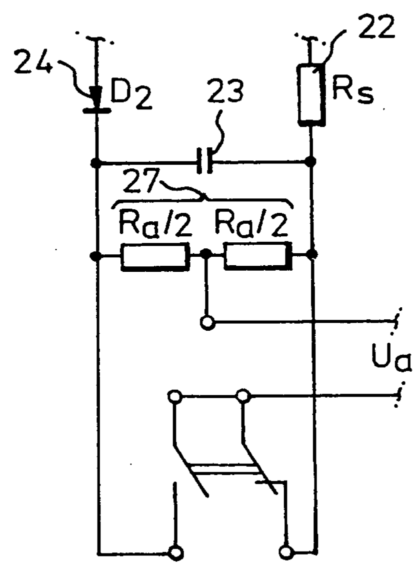


Fig. 6b.

SPECIFICATION

Alternating-current tachometer generator as analog signal emitter

The invention relates to an alternating-current tachometer generator as analog signal emitter, the output signal of which is in linear dependence, in amplitude and frequency, upon the rotation rate. By subsequent precision rectification and smoothing it is also possible, in order to widen the field of application, to convert the generated output signal into a direct-current voltage in linear dependence upon the rotation rate, the polarity of which voltage is controlled by the direction of rotation.

Alternating-current tachometer generators are known the output signals of which are in linear dependence, in amplitude and frequency, upon the rotation rate. Their principle of operation is based upon the single-phase or multi-phase synchronous generator with salient poles or claw-pole formation, also reluctance principles after the Lorenz or Guy construction style.

The known alternating-current tachometer generators all have the disadvantage that the magnetic iron circuit or a part thereof is energized by the alternating flux, so that the occuring magnetic hysteresis losses of the iron cause a relatively great deviation from linearity and a distortion of the curve form. Therefore the usable range of rotation rates of such embodiments is small. Moreover the construction requires high economic expense in production.

Furthermore direct-current tachometer generators with different operational principles are known as analog rotation rate indicators and photo-electric digital rotation rate indicators.

In direct-current tachometer generators there is a great susceptibility to faults in mechanical commutation so that the life is greatly reduced and/or expensive service work is necessary. While such generators with electronic commutation in part eliminate this disadvantage, at present however with acceptable expense they achieve only a large grooving factor, so that use in low rotation rate ranges is possible only if specifc pre-requisites are observed. The expense of manufacture of direct-current tachometer generators is also higher than that of alternating-current tachometer generators. Moreover there are great problems in alternating-current tachometer generators in the interpretation of the reversal of direction of rotation. Methods hitherto, in which two voltages staggered in time through 90° are generated and evaluated through phase discriminators, can indicate the direction of rotation only in accordance with the response sensitivity.

Photo-electric signal emitters generate an output signal which is not dependent in amplitude upon the rotation rate, so that when they are used as anal g signal emitters one is compelled to evaluate the p riod duration. This is effected by frequency/voltage converters which contain a low-pass filter for the achievement of a sufficiently low grooving factor and thus possess too great a time constant for many applications.

The aim of the invention consists in eliminating the stated disadvantages and developing a constructionally simple, operationally reliable alternating-current tachometer generator of medium frequency and high precision in which the recognition of direction of rotation is achieved with a very narrow range of error in the region of the zero point. The output signal is further to possess the advantage that digital and analog interpretation are possible. Furthermore by rectification and smoothing and reconnection a conversion into a direct-current voltage is to be achieved, the polarity of which voltage depends upon the direction of rotation. The aim also exists of effecting the conversion into a rotation-rate-proportional direct-current voltage by additional equipment, without or with auxiliary energy.

Moreover with the alternating-current tachometer generator the measurement of fluctuations of synchronism of rotating parts is to be possible with high precision, in that their magnitude is proportional to the F.M. signal modulated in output voltage.

In accordance with the invention this is achieved in that a multi-pole winding of meander form arranged in the air gap on non-magnetic material is energised by a magnetic flux of varying intensity. The variation of the magnetic flux is here achieved by a constantly changing maximum and minimum coupling to the winding, with the slot pitch corresponding to the pole pitch. The alternating magnetic couplings are achieved by appropriate grooving of the rotating energiser circuit in the region of the air gap, whereas the winding stands still.

With this arrangement, within the magnetic conductive circuit the magnetic flux always remains constant as a whole. Since thus the disadvantageous interference value due to magnetic hysteresis losses in the iron is entirely excluded, the linearity defect is now determined only by the armature reaction and the eddy currents in the conductors of the winding, and therefore is very small in total. The double-coated conductor material used for the production is used on both sides, and on the front and rear the conductors are arranged in relation to one another so that either their component voltages are added to one another or the component voltages possess a different course in time (multi-phase winding). The obtained analog alternating-current voltage can be utilised directly for the indication of the rotation rate, or it is converted, by a passive or active precision rectification with smoothing, with or without auxiliary energy, into an analog direct-current voltage signal.

The recognition of the direction of rotation is effectd by means of a micro-switch with mechanical principle of action, based upon the slipping clutch principle, or by photo- lectric scanning. As slipping clutch there is pr ferably used a sliding contact or the friction of a ball bearing between inner and outer race rings. The precision rectification can take place according to the diode compensation m thod without auxiliary energy, or with auxiliary energy by suitably connected operation amplifiers. In the case of the diode compensation method the error of the flux tension of the diode is compensated by a counter-connected second diode of the same type. Since temperature variations act upon both diodes

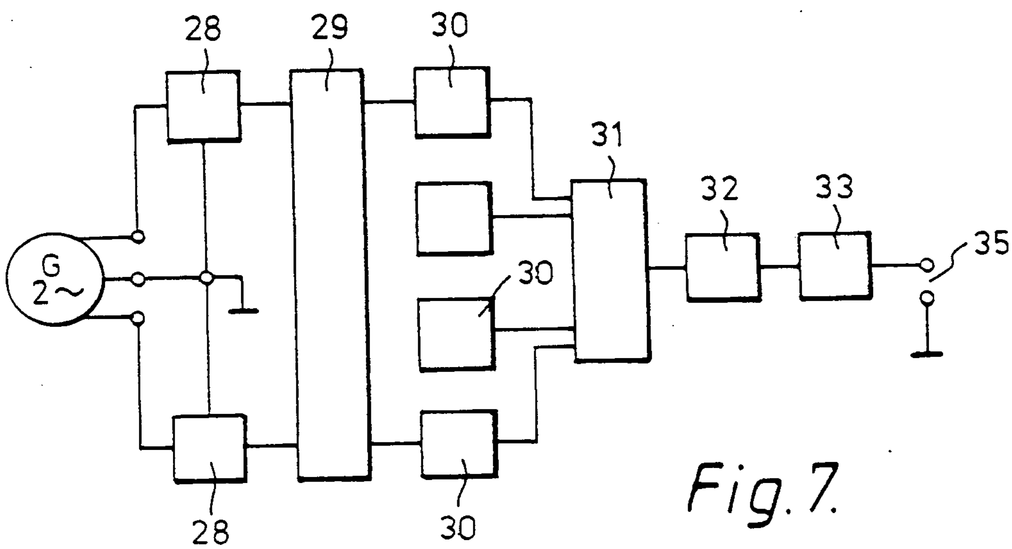


Fig. 7.

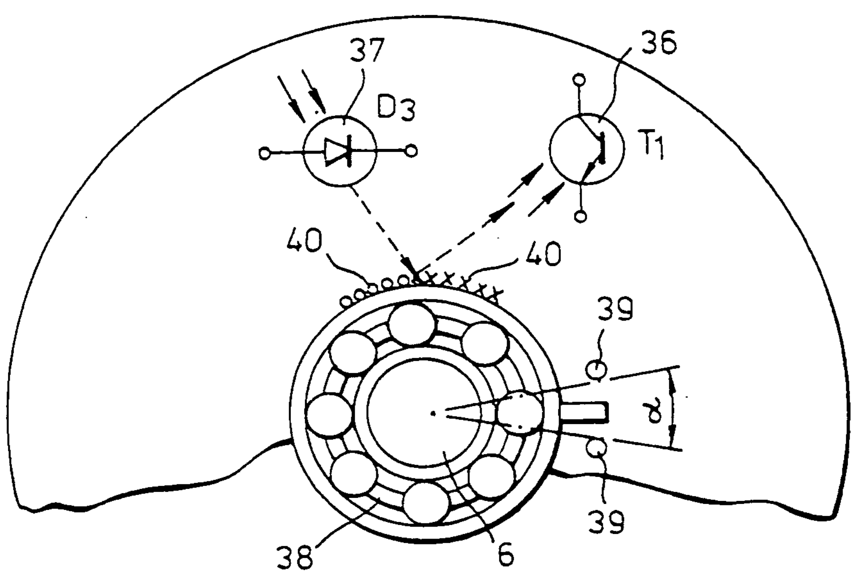


Fig. 8.

conductor plate 8 in Figure 2. N-phase windings are possible in principle by further division of the position of the windings in relation to one another on the conductor plate.

For the case of a single-phase voltage Figure 5 shows a precision rectification without auxiliary energy which makes the delivered power of the alternating-current tachometer generator G alone suffice. The alternating-current voltage of the alternating-curreny tachometer generator G is stepped up by the precision transformer (Tr_1) 19 in such a way that two symmetrical voltages E_1 and E_2 are present on the secondary winding 20 of the precision transformer (Tr_1) 19. With the aid of the rectifier diode (D_1) 21 the alternating-current voltage is rectified, and it is smoothed by the RC-filtration system, consisting of filter resistor (R_s) 22 and filter capacitor (C_s)23. The linearity defect of the rectifier diode (D_1) 21 is most extensively compensated by the compensation diode (D_2) 24 with the aid of the compensation current circuit 25.

For the balancing of the compensation current circuit 25 there serves the variable balance resistor (R_2) 26, which co-operates with the constant resistor (R_1). The smoothed direct-current voltage (U_a) proportional to the rotation rate is present on the working r sistor (R_a) 27.

If the direction of rotation is to be displayed in the form of the polarity reversal of the direct-current voltage the principle rectification according to Figure 5 is to be assembled a second time and their direct-current voltages are to be added according to Figure 6*a*, or the working resistor (R_a) 27 is divided according to Figure 6*b* into two halves. The mechanical switch is driven by a slipping clutch.

Figure 7 shows, for a two-phase alternating-current tachometer generaor G, a precision recitification with auxiliary energy, the signal-processing parts of which are realised by loaded operation amplifiers. Differences of amplitude between the 90° phase-shifted voltages are compensated with the input amplifiers 28. Four 45° phase-shifted voltages are generated by a weighted summation 29 from the two 90° phase-shifted voltages. Each of these voltages is precision-rectified by means of what are called ideal diodes 30 before the addition of all rectified voltages takes place in the adder 31 and the adaptation is effectd to the unit signal level to be realised. In dependence upon the binary rotation-direction signal 34 gained on the alternating-current tachometer generator G the change-over switch 32 acts invertingly or non-invertingly, whereby the polarity of the output signal 35 is determined. The desired grooving factor and the termination condition corresponding to the output signal 35 - a very small internal resistance for voltage signals or a very great internal resistance for current signals - are realised with the active low-pass filter 33. In the case of precision rectification with auxiliary energy it is expedient to utilise an electronic switch, consisting of light-emitter diode (D_3) 37 and photo-transistor (T_1) 36, which generates a binary signal controlled by the direction of rotation.

Due to this principle, s e Figure 8, it is possible to use a very wear-resistant slipping clutch in the form of a ball bearing 38. In this case the inner race ring of the ball bearing 38 is firmly connected with the shaft 6 and its outer ring is arrested with the pins 39 at an angle α. At the same time on the outer race ring of the ball bearing 38, in the region of the angle α, the fitting takes place of two different reflection coatings 40 over the angle α/2. Thus one obtains an opening/blocking of the photo-transistor (T_1) 36 in the one direction of rotation and a closing/conduction in the other.

List of references utilised

1 magnet yoke
2 magnet yoke
3 permanent magnet
4 hub
5 cylindrical pin (with point)
6 shaft
7 counersunk screw
8 conductor plate
9 winding of meander form
10 countersunk screw
11 securing flange
12 cylindrical screw
13 air gap
14 air gap
15 end face
16 bore
17 grooving
18 sine-wave voltage
19 precision transformer (Tr_1)
20 secondary winding
21 rectifier diode (D_1)
22 filter resistor (R_s)
23 filter capactitor (C_s)
24 compensation diode (D_2)
25 compensation current circuit
26 balance resistor (R_2)
27 working resistor (R_a)
28 input amplifier
29 weighted totalling
30 ideal diode
31 adder
32 change-over switch
33 active low-pass filter
34 binary rotation-direction signal
35 ouput signal
36 photo-transistor (T_1)
37 light-emitter diode (D_3)
38 ball bearing
39 pin
40 reflection coating
E_1 voltage
E_2 voltage
G alternating-current tachometer generator
U_a direct-current voltage
R_1 constant resistance
α angle
τp pole pitch

CLAIMS

1. Alternating-current tachometer generator as analog signal mitter, which generates a single-phase or multi-phas voltage which is proportional

at the same time, such an arrangement is temperature-stable to a high degree. For the rectification with counter-connected diode a precision transformer is required the magnetic circuit of which consists of highly permeable magnetic material, to keep the transmission error and the magnetisation current, which reacts though the alternating-current tachometer generator internal resistance, small. The same precision transformer can also be used for voltage adaptation for existing indicator instruments in the case of the direct use of the alternating-current voltage signal as already described above. If auxiliary energy is fed to the apparatus it is possible, with appropriately connected operation amplifiers to realise temperature-stable precision rectifiers linear within wide limits - known as ideal diodes, in series after which an active low-pass filter is connected in order to achieve a low grooving effect. Such an arrangement permits the conversion of the single-phase or multi-phase tachometer alternating-current voltage into an output voltage or an output current. The interpretation of the frequency takes place according to usual methods. Since in alternating-current tachometer generators the frequency of the output signal is proportional to the rotation rate, fluctuations of synchronism are present on principle as F.M. signals. While in the case of all principles of operation hitherto, for example in photo-electric signal emitters, defects of pitch of the perforated disc simulate a fluctuation of synchronism, in the case of the winding embodiment according to the invention defects of pitch in the conductors and the pole geometry and asymmetries in the air gap have no influence upon the generated fequency. Thus fluctuations of synchronism are displayed with high precision as F.M. signal.

The invention is to be explained hereinafter by reference to an attachable alternating-current tachometer generator. In the accompanying drawing:-

Figure 1 shows an overall view of the attachable alternating-current tachometer generator,

Figure 2 shows a conductor plate with winding of meander form,

Figure 3 shows a magnet yoke with axially acting grooving

Figure 4 shows the principle of the magnetic flux course in the air gap and its coupling to the conductors,

Figure 5 shows precision rectification without auxiliary energy,

Figure 6a shows mechanical switching-over of the polarity - addition of the direct-current voltages,

Figure 6b shows mechanical switching-over of the polarity - division of the working resistance,

Figure 7 shows precision rectification with auxiliary energy,

Figure 8 shows an arrangement for the recognition of the reversal of direction of rotation.

Th rotating part of the alternating-current tachometer g nerator G according to Figure 1, consisting of the two magn t yokes 1 and 2, the annular permanent magnet 3 and the countersunk screws 7, is connected rigidly in rotation with the shaft 6 by the hub 4 and the cylindrical pin 5 (with point).

The conductor plate 8 acc rding t Figure 2 with the winding 9 of the meander form is firmly connected with the housing of the driving machine by the countersunk screw 10 by way of the securing flange 11 and the cylindrical screws 12.

The permanent magnet 3 is magnetised in the axial direction, so that the magnetic flux proceeds by way of the cup-shaped magnet yokes 1 and 2 according to Figure 3, by way of the two air gaps 13 and 14 to left and right of the conductor plate 8, and through the latter itself.

In order to keep the magnetic stray flux small, the hub 4 and the countersunk screws 7 consist of non-magnetic material. In order to achieve a precise centring of the rotating parts, there are closed fits between the permanent magnet 3 and the magnet yokes 1 and 2, from the magnet yoke 1 to the hub 4, from the hub 4 to the shaft 6, and from the magnet yoke 2 to the shaft 6. The countersunk screws 7 serve for the firm pressing of the two magnet yokes 1 and 2 upon the permanent magnet 3 and at the same time of the hub 4 upon the magnet yoke 1, whereby a very high strength of the rotating part is achieved. The division of the conductor plate 8 into two halves according to Figure 2 achieves the object that in assembly firstly the complete rotating part is aligned axially in relation to the end face 15 of the securing flange 11 on the shaft 6 and can be arrested firmly on the shaft 6 by means of a cylindrical pin 5 (with point) through the bore 16 of the hub and engaging in a centre hole in the shaft 6, and only then the two halves of the conductor plate 8 are pushed laterally into the air gaps 13 and 14 and fixed on the securing flange 11 by means of countersunk screws 10. Securing of the (pointed) cylindrical pin 5 against rotation can be effected by varnishes or resins.

Due to the grooving 17 of the magnet yokes 1 and 2 according to Figure 3 a magnetic coupling according to Figure 4 is achieved differing from the winding 9 of meander form according to Figure 2. The positions I to IV in Figure 4 clarify the different coupling, whereby a sine-wave voltage is generated on rotating movement. At the same time it can be seen clearly from Figure 4 that the direction of flux and the magnetic flux in the air gaps 13 and 14 and in the iron circuit always remain constant.

The right half of the conductor plate 8 in Figure 2 shows a winding 9 of meander form, the conductors of which are so arranged on the front and back that the sine-wave voltages 18 are added directly in the case of phase angle 0°.

If the winding 9 of meander form is continued on the left half of the conductor plate 8 at the interval *a*. pole pitch τp, on the front and rear of the plate, all four component voltages are added in the phase angle 0° and a single-phase winding is produced.

If however the winding of meander form is continued on the left half of th conductor plate 8 at th interval *a* . p le pitch τp + pole pitch $\tau p/4$, th n th voltages generated from the left and right halves of the conductor plate 8 are shifted in phase by 90°, and thus a two-phase winding is produced.

A four-phase winding is likewise possible if f r example the winding 9 of meander form is three-dimensionally offset on front and r ar by the pole pitch $\tau \pm /8$, as indicat d on th left half of the

in amplitude and frequency to the rotation rate, characterised in that a multi-pole winding (9) of meander form arranged in the air gap on non-magnetic material is energised on movement by a magnetic flux of like direction constantly varying in intensity, as the variation of the magnetic flux is achieved by constantly changing minimal and maximal coupling to the winding (9) of meander form with the aid of the grooving (17) of the magnet yokes (1 and 2) and the pole pitch conforms with the winding (9) of meander form, the grooving (17) of the magnet yokes (1 and 2) being situated axially oppositely on the two sides of the conductor plate (8), while the magnetic flux as a whole remains constant within the magnetic circuit.

2. Alternating-current tachometer generator according to Claim 1, characterised in that the conductor plate (8) with the winding (9) of meander form is stationary and the magnet yokes (1, 2) with the grooving (17) carry out the rotating movements.

3. Alternating-current tachometer generator according to Claims 1 and 2, characterised in that the conductor plate (8) is double lined or of multi-layer formation, the individual parts or layers of the winding (9) of meander form being three-dimensionally arranged in their phase angle in relation to one another in such a way that symmetrical, multi-phase windings are produced.

4. Alternating-current tachometer generator according to Claims 1 and 2, characterised in that the conductor plate (8) with the winding (9) of meander form is divided into two halves, to simplify assembly, and is centred by means of countersunk screws (10) on the securing flange (11).

5. Alternating-current tachometer generator according to Claims 1, 3 and 4, characterised in that in the case of two-phase formation the four windings (9) on the two conductor plate halves are electrically wired so that the amplitude differences and phase defects, due to the tolerances in the conductor plate manufacture and in assembly, between the two voltages are largely compensated.

6. Alternating-current tachometer generator according to Claims 1 and 2, characterised in that in order to achieve a high effective flux in the air gaps (13, 14), the countersunk scres (7) and the hub (4) consist of non-magnetic material.

7. Alternating-current tachometer generator according to Claims 1 and 2, characterised in that in order to achieve high voltages the axially magnetised permanent magnet (3) is of annular formation and consists of magnetic materials of high energy density.

8. Alternating-current tachometer generator according to Claims 1 and 2, characterised in that to reduce the displacement of centre of gravity, close fits are provided betwe n the magnet yokes (1, 2), the permanent magnet (3), the magnet yoke (1) and the hub (4), the magnet yoke (2) and the shaft (6) and the hub (4) and the shaft (6).

9. Alternating-current tachometer generator accordng to Claims 1 and 2, characteris d in that the rigid connection in rotation with the shaft (6) through the hub (4) is effected by means of a (pointed) cylindrical pin (5) whereby an axial fixing is achieved at the same time.

10. Alternating-current tachometer generator according to Claims 1, 2 and 9, characterised in that the (pointed) cylindrical pin (5) is secured with the hub (4) against slackening, by means of varnishes or resins.

11. Alternating-current tachometer generator according to Claims 1 and 3, characterised in that the single-phase or multi-phase alternating-current voltage is converted, with or without auxiliary energy, by precision rectification and smoothing, into an analog direct-current signal.

12. Alternating-current tachometer generator according to Claims 1 and 11, characterised in that the precision rectification takes place without auxiliary energy by means of precision transformer (Tr_1) (19) and counter-connected compensation diode (D_2) (24).

13. Alternating-current tachometer generator according to Claims 1 and 12, characterised in that the precision transformer (Tr_1) (19) works with very low magnetic field intensity, and its magnet circuit consists of highly permeable materials, in order to keep the transformation error small.

14. Alternating-current tachometer generator according to Claims 1, 12 and 13, characterised in that the rectifier diode (D_1) (21) used for rectification and the compensation diode (D_2) (24) used for compensation are of the same type, for the most extensive suppression of the temperature error.

15. Alternating-current tachometer generator according to Claims 1 and 13, characterised in that the precision transformer (Tr_1) (19) serves for the voltage adaptation of indicator instruments which are present.

16. Alternating-current tachometer generator according to Claims 1 and 11, characterised in that the precision rectification and smoothing take place with auxiliary energy by means of operation amplifier circuit arrangements.

17. Alternating-current tachometer generator according to Claims 1 and 16, characterised in that in the case of multi-phase embodiments amplitude differences between the voltages are compensated with the aid of the input amplifiers (28) and by weighted totalling (29) additional phase-shifted signals are gained.

18. Alternating-current tachometer generator according to Claims 1 and 16, characterised in that the precision rectification of all phase-shifted voltages is effected by means of operation amplifier circuit arrangement or ideal diode (30), the addition of the rectified signal with simultaneous adaptation to the unit level is effected by means of adder (31) and this signal is transmitted by the change-over switch (32) invertingly or non-invertingly in dependenc upon the binary rotation-direction signal (34) gained at the tachom ter gen rator (G).

19. Alternating-current tachometer generator according to Claims 1 and 16, characterised in that the smoothing on the output side tak s place with the aid of an active low-pass filter (33), while at the same time the termination conditions valid for unit signals are produced.

20. Alt rnating-current tachometer generator

according to Claim 1, characterised in that the frequency-modulated part of the output signal is interpreted electronically for the measurement of fluctuations of synchronism.

21. Alternating-current tachometer generator according to Claims 1, 11 to 14 and 16 to 18, characterised in that the recognition of direction of rotation is effected by pole reversal of the direct-current voltage by means of mechanical or photo-electric switches.

22. Alternating-current tachometer generator according to Claims 1 and 21, characterised in that the mechanical drive of the change-over switches takes place according to the slipping clutch principle.

23. Alternating-current tachometer generator according to Claims 1, 21 and 22, characterised in that for the polarity reversal according to photo-electric methods for the achievement of a high reliability, the slipping clutch is formed as a ball bearing (38) and its inner race ring is rigidly connected with the shaft (6) and the outer race ring is arrested by the pins (39) on the angle α, while at the same time on the outer race ring, in the region of the angle α, over the angle $\alpha/2$ two different reflection coatings (40) are provided which cause an opening/blocking of the photo-transistor (T_1) (36) in the one direction of rotation and a closing/conduction in the other.

24. An alternating-current tachometer generator substantially as described with reference to the accompanying drawings.

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